Particulate Matter Sources in Birmingham, Alabama

Synopsis

July 14, 2006

Prepared by

Charles Blanchard[1]

George Hidy[1]

Shelley Tanenbaum[1]

Eric Edgerton[2]

[1] Envair

526 Cornell Avenue

Albany CA 94706

[2] Atmospheric Research and Analysis

410 Midenhall Way

Cary NC 27513

Prepared for

Alabama Department of Environmental Management

and

Jefferson County Department of Health

SYNOPSIS OF REPORT[1]

The Problem

Measurements of airborne particles at two Birmingham air-quality monitoring sites, located in North Birmingham (NBHM) and Wylam (WYL), show high airborne particle concentrations relative to other sites in urban and non-urban portions of Jefferson County, Alabama. The annual average concentrations of fine particulate matter (fine PM, or particulate matter less than 2.5 micrometer (μm) aerodynamic diameter, $PM_{2.5}$) at NBHM and WYL exceed the current National Ambient Air Quality Standard (NAAQS) (annual average 15 micrograms per cubic meter [$\mu g\ m^{-3}$]), thereby requiring the state to provide formal plans for their reduction. The State Implementation Plan (SIP) for reduction of $PM_{2.5}$ concentrations must be submitted to the U.S. Environmental Protection Agency (EPA) by April 2008. Formally, the SIP must identify specific fine particle emission control measures that will be implemented and that will allow NBHM and WYL to attain the fine PM NAAQS by the 2010 attainment target.

EPA has designated Birmingham a non-attainment area for fine PM, with a 2002-2004 design value (DV, a three-year average of the annual average fine PM mass concentrations) of 16.8 $\mu g\ m^{-3}$, which is a spatial average (community monitoring zone, or CMZ) of the corresponding values of 16.0 $\mu g\ m^{-3}$ at WYL and 17.5 $\mu g\ m^{-3}$ at NBHM. Other sites in Jefferson County where fine particle concentrations are monitored for compliance with the NAAQS are located in Pinson, Corner, Leeds, Providence, McAdory, and Hoover. The 2002-2004 annual average fine PM mass concentrations at these other sites did not exceed the NAAQS; however, the annual averages of 14.3 $\mu g\ m^{-3}$ at Hoover and 14.6 $\mu g\ m^{-3}$ at McAdory were near the level of the NAAQS.

Daily-average PM_{10} (particulate matter less than 10 micrometer (μm) aerodynamic diameter) mass measurements were made at eight additional sites from 2000 through 2004 (Tarrant, Sweet Avenue [ABC], Shuttlesworth Drive [Sloss], Birmingham - 11th Avenue [Northside], Fairfield, Bessemer –Williamson [Dolomite], Bessemer - 1st Avenue [Bessemer], Leeds), with samples collected once every six days. The only locations with fine PM measurements in mid-town Birmingham were WYL and

[1] This synopsis presents project findings of relevance to federal regulatory requirements.

NBHM, and formal plans for compliance will therefore necessarily focus on WYL and NBHM. However, it should be noted that mean annual PM_{10} concentrations at Fairfield, Bessemer 1st Ave, and Tarrant were approximately the same as the corresponding mean annual PM_{10} concentrations at WYL, Sweet Avenue mean PM_{10} concentrations exceeded those at WYL, and Shuttlesworth Drive mean PM_{10} concentrations exceeded those at NBHM. It is therefore possible that fine PM mean concentrations in various portions of Birmingham exceeded the NAAQS level of 15 $\mu g\ m^{-3}$, but are not known simply because no fine PM monitoring record exists for mid-town locations other than NBHM and WYL. Both NBHM and WYL are located in areas of the city that are highly industrialized and that are also partially residential.

Monitoring results indicate that a larger region, including more rural portions of Jefferson County and surrounding portions of the state, has annual-average $PM_{2.5}$ concentrations of 12 to 14 $\mu g\ m^{-3}$, approaching the ambient air quality standard of 15 $\mu g\ m^{-3}$ annual average. Superimposed on these high regional levels is a diffuse urban concentration increment of approximately 2 $\mu g\ m^{-3}$. In the case of NBHM and WYL, an additional highly localized increment of 3 to 4 $\mu g\ m^{-3}$ is also present.

Reduction of both regional and urban source contributions to mean $PM_{2.5}$ mass concentrations will be needed for attaining the $PM_{2.5}$ NAAQS. The regional contribution to annual-average fine PM mass concentrations, which is about 12 to 14 $\mu g\ m^{-3}$, creates a narrow margin for local PM emissions. PM emission regulations that have been adopted by the EPA, and which will apply to both electric utilities and to mobile sources, are projected to lower regional fine PM concentrations by about 1 $\mu g\ m^{-3}$ by 2010. Attainment of the fine PM NAAQS in Jefferson County will also require reductions of local PM contributions, especially around the NBHM and WYL sites.

Regional and General Urban Fine PM

The annual average fine PM concentrations at both urban and non-urban sites are strongly influenced by sulfate (as ammonium salts), carbon compounds, and to a lesser degree, nitrate and elemental species, including a variety of metallic species. Modeling studies project that the regional and general (or diffuse) urban components of $PM_{2.5}$ will decline by about 1 $\mu g\ m^{-3}$ over the next several years with reduction in sulfate, nitrate,

and carbon concentrations, as a result of controls on emissions of sulfur dioxide (SO_2) and oxides of nitrogen (NO_x= NO + NO_2) applied to large stationary sources and of controls on transportation emissions of NO_x, SO_2, and primary PM (cleaner gasoline and diesel vehicles).

Analyses of carbon isotopes (carbon 14, or ^{14}C) in samples collected at NBHM and at Centreville (CTR), located in Bibb County approximately 85 km southwest of Birmingham, have established the fractions of modern (due to biomass combustion) and fossil (due to fossil-fuel combustion) carbon at this pair of monitoring sites. On average, carbon compounds at NBHM were 60 percent of fossil origin and 40 percent modern. The modern carbon levels at Centreville and North Birmingham (NBHM) were nearly identical from day to day, thus demonstrating the regional character of modern carbon. In contrast, the daily-average fossil carbon concentrations were dramatically greater at North Birmingham than at Centreville, thus unambiguously demonstrating that urban or local sources account for most of the fossil-fuel derived carbon at North Birmingham. These results imply that carbon concentrations at North Birmingham could be reduced by addressing urban transportation emissions as well as emissions from stationary sources that use coal and other fossil fuels.

Carbon compounds (total carbon, or TC) are routinely differentiated by standard measurement methods as organic carbon (OC) and as elemental carbon (EC; alternatively known as black carbon [BC]). The carbonaceous material at North Birmingham was on average approximately 70 percent OC and 30 percent EC. Local emissions contributed to both OC and EC, but in different proportions. OC was approximately two-thirds regional, modern OC and one-third local, fossil OC. EC was primarily due to fossil-fuel emissions and on average was one-third regional and two-thirds local (or urban) EC. Overall, total carbon at NBHM was about one-half regional and one-half urban in origin.

Local Fine PM

The PM chemical composition at NBHM and WYL is similar to that found at regional and non-urban sites, except that additional (mainly fossil C related) carbon (as OC and EC) is found at NBHM and WYL, along with certain metal concentrations, which are substantially higher than in other cities. Compared with a rural monitor

located in Providence, the mean fine mass concentrations were 4.6 $\mu g\ m^{-3}$ higher at WYL and 5.8 $\mu g\ m^{-3}$ higher at NBHM. Inorganic species (sulfate, nitrate, and ammonium) accounted for 1.2 to 1.5 $\mu g\ m^{-3}$ of the excess mass at the two urban sites, and organic carbon represented 1.0 $\mu g\ m^{-3}$ of the excess at WYL and 2.2 $\mu g\ m^{-3}$ of the excess at NBHM. Because the measurements of OC record only the mass of carbon contained in organic carbonaceous compounds, the actual mass of organic material (OM) is conventionally estimated to be about 40 percent greater than the measured OC mass. Elemental carbon represented 0.4 $\mu g\ m^{-3}$ of the excess at WYL and 1.0 $\mu g\ m^{-3}$ of the excess at NBHM. The sum of the elemental concentrations of aluminum, bromine, calcium, chlorine, chromium, copper, iron, lead, magnesium, manganese, nickel, silicon, sodium, titanium, and zinc, denoted here as "elements", added another 1.2 $\mu g\ m^{-3}$ of the excess at WYL and 0.5 $\mu g\ m^{-3}$ of the excess at NBHM, on average. The relative proportions of the species contributions to the excess mass differed at WYL and NBHM, with greater excess OC and EC at NBHM and more excess elemental mass at WYL.

While major species concentrations at Birmingham sites are similar to, or somewhat larger than, at other urban Southeast locations, certain elemental species concentrations are very different. The most striking is zinc, whose average concentrations are two orders of magnitude greater at North Birmingham and Wylam than at any other urban location in the southeastern US. Zinc, therefore, is apparently a chemical marker for emissions that are largely unique to Birmingham. Since mobile source emissions are common to all cities, zinc emissions in Birmingham derive from specific industrial processes occurring there. Other species present at higher concentrations at the Birmingham sites are calcium, copper, chromium, iron, manganese, sodium, and lead. All indicate the presence of specific emission sources that influence local PM levels in Birmingham, but these elements are not necessarily unique to any specific facility.

The topography and weather conditions in Birmingham tend to force prevailing surface winds to be most frequent parallel to a shallow depression running from northeast to southwest. This valley includes most of the manufacturing, industrial and commercial activity of the city and contains most of the heavy highway traffic.

Stationary sources within 10 km of NBHM include three steel pipe manufacturers, two large coking operations, a mineral wool plant, an asphalt batching plant and fugitive sources from coal and coke storage yards, a limestone quarry, and metal fabricating operations. The NBHM site is also near two major interstate highways, and heavy local traffic, including substantial railroad traffic with diesel locomotives, occurs around the nearby manufacturing plants. The highest hourly-average PM concentrations at NBHM occurred when winds were from ~20 to 70 degrees (Figure 1), in line with four major PM sources (no interstate highways are located in this direction). In addition, high hourly-average PM concentrations also occurred when winds were from the southeast, in line with several other PM sources.

At WYL, the local sources potentially of concern include a large steel manufacturing operation to the southwest, including an area for coke and product storage and an extensive area of slag and sludge storage; smaller manufacturing activity also exists ~0.5 km to the east and northeast, including a metal processing company, railroad yards and road or interstate highway traffic. At WYL, the highest mean PM concentrations were associated with winds from ~ 0 to 130 degrees, directions lacking major PM point sources but in line with several small PM point sources, a rail line, and Interstate 20 (Figure 1). Enhanced PM concentrations were also found at WYL with winds from ~200 to 250 degrees, in the direction of a slag pile and the US Steel facility and perhaps manufacturing further down-valley to the SSW (Figure 1).

The local origins of PM emissions affecting the PM concentrations at NBHM are further established through consideration of PM concentrations at monitoring locations upwind of specific emissions sources. With winds from the northeast, hourly PM_{10} concentrations were low at Sweet Avenue, higher at Shuttlesworth Drive, and highest at NBHM (Figure 2), indicating the cumulative impact of four major PM sources and associated industrial activity located between Sweet Avenue and NBHM. Similarly, the nearest upwind $PM_{2.5}$ monitor, located at Pinson High School, showed much lower hourly PM concentrations when winds were from the northeast than did NBHM. The evidence linking specific facilities with $PM_{2.5}$ at NBHM is discussed next.

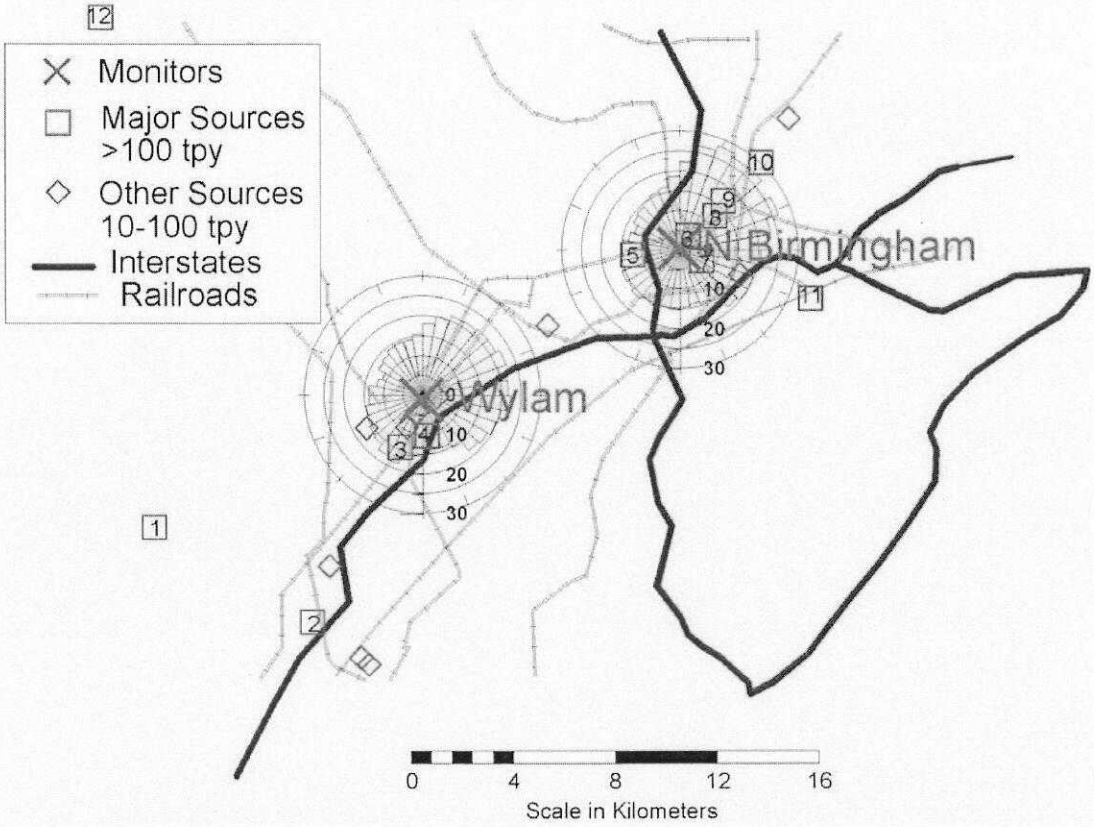

Figure 1. Mean directional $PM_{2.5}$ concentrations at NBHM and WYL compared with the locations of PM emission sources, highways, and railroads. The directions of origin of the winds corresponds to compass degrees. The mean $PM_{2.5}$ concentrations associated with each direction are indicated by the lengths of the bars, with the scale being proportional to the radii of the concentric circles as indicated by their labels (measurement units are $\mu g\ m^{-3}$). Major PM emissions sources are numbered as follows: (1) Oak Grove Resources, LLC, (2) U.S. Pipe & Foundry Company, LLC (Bessemer), (3) U.S. Steel Corporation (Fairfield), (4) U.S. Steel Corporation (Fairfield pipe mill), (5) American Cast Iron Pipe, (6) U.S. Pipe & Foundry Company, LLC (N. Birmingham), (7) Nucor Steel, (8) Sloss Industries (coke), (9) Sloss Industries (mineral wool), (10) ABC Drummond Company, Inc., (11) SMI Steel, (12) Alabama Power Company (Miller plant).

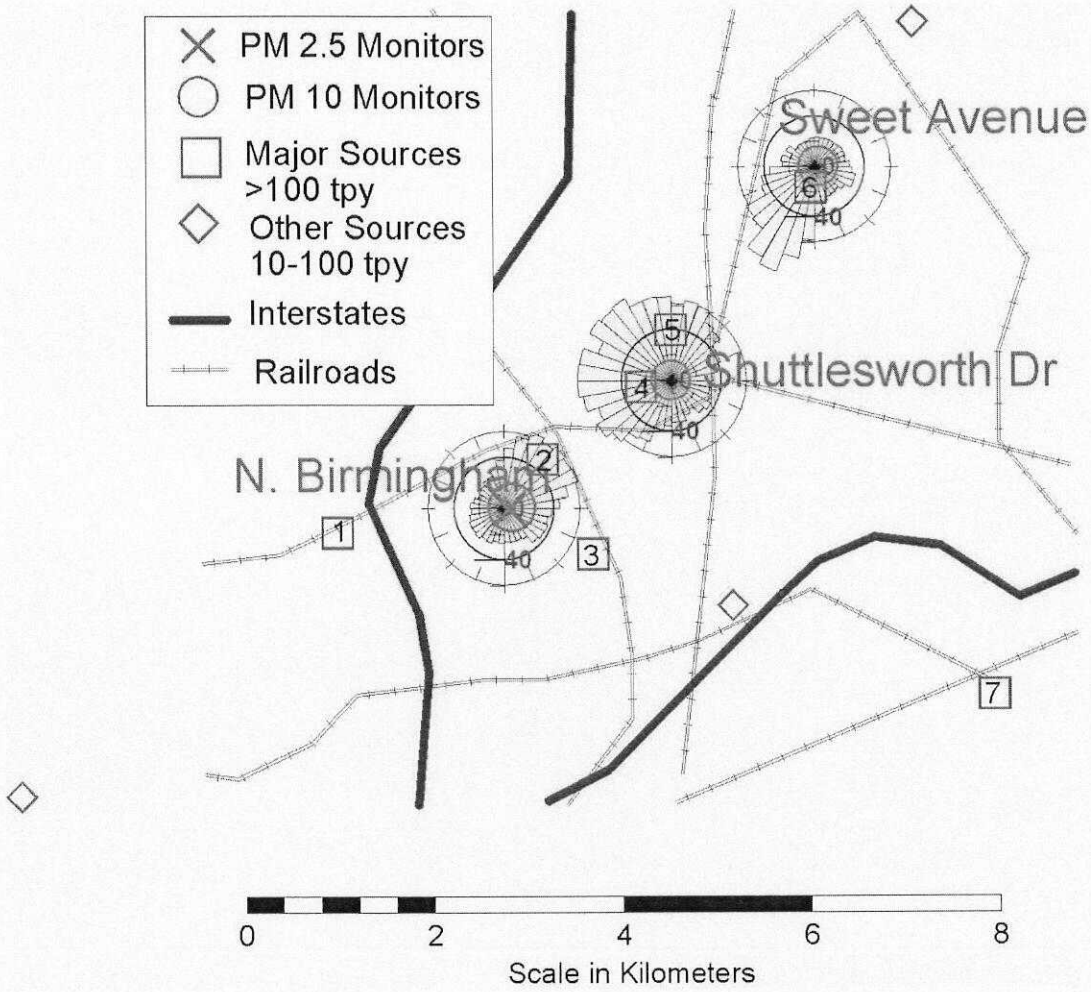

Figure 2. Mean directional PM_{10} concentrations at North Birmingham, Shuttlesworth Drive, and Sweet Avenue compared with the locations of PM emission sources, highways, and railroads. The directions of origin of the winds correspond to compass degrees. The mean PM_{10} concentrations associated with each direction are indicated by the lengths of the bars, with the scale being proportional to the radii of the concentric circles as indicated by their labels (units are $\mu g\ m^{-3}$). Major PM emissions sources are numbered as follows: (1) American Cast Iron Pipe, (2) U.S. Pipe & Foundry Company, LLC (N. Birmingham), (3) Nucor Steel, (4) Sloss Industries (coke), (5) Sloss Industries (mineral wool), (6) ABC Drummond Company, Inc., (7) SMI Steel.

Evidence for Stationary Source Contributions to $PM_{2.5}$ Concentrations at NBHM

U.S. Pipe and Foundry, North Birmingham. The nearest major industrial source to the NBHM site is the U.S. Pipe and Foundry Company, located about 0.45 km east of NBHM. In 2003, it was the ninth-largest fine PM stationary emissions source in Jefferson County. The evidence linking its emissions with fine PM concentrations at NBHM includes:

- Proximity and magnitude of PM emissions.
- Enhanced hourly fine PM concentrations when winds were from the direction of the facility.
- Observed dark plumes emanating from the facility.[2]
- Strong correlations between hourly concentrations of $PM_{2.5}$ mass and gas-phase pollutants emitted as combustion products, including CO, NO, and SO_2.
- Reduced concentrations of elemental carbon (EC) and certain metals, including iron, zinc, and manganese, on Saturdays and Sundays, consistent with process shutdown at this facility on weekends.
- Higher ratios of $PM_{10}/PM_{2.5}$ at NBHM than at WYL and other sites, indicating the importance of nearby emission sources.
- Short-duration (one to three hours) spikes in $PM_{2.5}$ mass concentrations at NBHM that are uncorrelated with hourly PM concentrations at other area monitoring sites and which frequently occurred close to 6 am, usually on weekdays (i.e., indicating proximate emissions potentially associated with intermittent process activities occurring at scheduled times).

Sloss Industries and ABC Drummond, North Birmingham. Two large coke production facilities are situated to the northeast of NBHM; these are the Sloss facility (about 1.8 km northeast), and the ABC Drummond operations (about 4.5 km northeast of NBHM). The Sloss mineral wool plant is adjacent to the Sloss coking operations, about 2.3 km northeast of the NBHM site. An asphalt batch plant is situated just west of the

[2] Such plumes have been observed on occasion but have not been recorded systematically or sampled for PM, so it is not possible to correlate with observations with measurements of fine PM at NBHM.

Sloss coke production plant. A large quarry producing crushed limestone (calcium carbonate) exists adjacent to the ABC plant. In addition to process-related PM emissions from coke and mineral wool production, fugitive emissions are expected to be associated with the coal and coke crushing and storage yards. Also expected are emissions from rail yards, from diesel trucks, and from excavation vehicles used in the quarrying operations. The focus of this analysis is on the largest PM emission sources, namely, the coke and mineral wool production processes; however, fugitive, rail, trucking, and quarrying emissions may also contribute to the overall total within this relatively small area. In 2003, the Sloss coke, ABC Drummond, and Sloss mineral wool facilities were the 3rd, 4th, and 12th largest fine PM stationary emissions sources in Jefferson County. The evidence linking their emissions[3] with fine PM concentrations at NBHM includes:

- Proximity and magnitude of PM emissions.
- Enhanced hourly fine PM concentrations at NBHM when winds were from the direction of the facilities, especially at night and during weekends (i.e., during times of operation for coke production but of process shutdown at many area metals manufacturing facilities).
- Unambiguous increases in PM_{10} concentrations at the Shuttlesworth Drive (Sloss) and Sweet Avenue (ABC Drummond) monitoring locations when winds were from the direction of the facilities (i.e., confirming the existence of high PM emissions indicated by the emission inventory).
- Strong correlations between hourly concentrations of $PM_{2.5}$ mass and gas-phase pollutants emitted as combustion or pyrolysis products, including CO, NO, and gaseous sulfur, as SO_2.
- Ratios of EC/OC averaging 1.3 to 1.7 at fence-line samplers, consistent with elevated EC/OC ratios at NBHM.
- High concentrations of silicon, calcium, potassium, and iron in fence-line samples.[4]

---

[3] Including possible contributions from fugitive emissions, rail yards, diesel trucking, quarrying, and asphalt production that have not to date been separable from direct process emissions.

[4] Indicating potential contributions of the facilities to these species concentrations at NBHM; other emission sources could also affect NBHM.

- Reduced concentrations of PM_{10} mass concentrations on Saturdays and Sundays at Shuttlesworth Drive, Sweet Avenue, and NBHM (i.e., demonstrating weekend reductions of PM emissions adjacent to coke and mineral wool production facilities[5] and at NBHM).

American Cast Iron Pipe Company (ACIPCO). The ACIPCO facility is located about 1.9 km to the west-southwest of NBHM. In 2003, it was the 5th-largest stationary source of fine PM emissions in Jefferson County, having emissions almost equal to those of ABC Drummond. The evidence linking its emissions with fine PM concentrations at NBHM includes:

- Small hourly PM enhancements when winds were from the direction of the ACIPCO facility (directions from 220 to 250 degrees).
- Higher hourly mean PM concentrations at NBHM than at McAdory and Hoover on days when prevailing surface and upper-level winds were from the southwest, with PM concentration differences of about 5 $\mu g\ m^{-3}$ from midnight to 7 am and about 2 $\mu g\ m^{-3}$ at other hours.
- High concentrations of elements, including silicon, potassium, calcium, and iron, in samples collected at the ACIPCO fence line.

Nucor, McWane, SMI, and Other Facilities. The two largest major PM sources located southeast of NBHM are Nucor Steel, 1.1 km distant, and SMI Steel, 5.7 km away; these facilities are the 13th and 11th largest stationary PM sources, respectively, in Jefferson County, each with emissions approximately equal to those of the Sloss mineral wool plant. Other facilities to the southeast are KMac (0.8 km, no PM emissions), McWane Cast Iron Pipe Company, (2.7 km, 14th largest), Induron Coatings (2.8 km, 24th largest), and other small facilities. Facility-specific impacts on PM at NBHM cannot be determined, but the following evidence collectively links facilities to the southeast of NBHM with PM there:

[5] These weekend reductions have not been linked with specific processes and potentially include reduced on-site or near-site transportation activities as well as production processes.

- Enhanced hourly fine PM concentrations at NBHM when winds were from the direction of the facilities (southeast).
- Highly elevated metals (nickel and chromium) concentrations in three samples associated with winds from the southeast.
- High concentrations of silicon, calcium, potassium, and iron in fence-line samples.

Evidence for Stationary Source Contributions to $PM_{2.5}$ Concentrations at WYL

USS (USX) Steel Operations-Fairfield. A very large historic steel plant is located to the southwest, with major emissions at approximately 1.6 and 2.2 km from WYL, and with slag piles nearly adjacent to WYL. This plant continues to be capable of operating a large blast furnace, oxygen-induction furnaces, a seamless tube manufacturing operation, and hot and cold rolled sheet metal operation, including galvanized sheet lines. In addition, there is substantial potential for fugitive dust suspension with trucking and railroad activity on-site, including coke storage and transfer, as well as other raw material storage facilities and the slag and debris storage areas. The area includes the Fairfield Pipe Mill (1.6 km from WYL, 8th-largest PM source in Jefferson County), the Fairfield plant (2.2 km, 2nd largest), Harbison-Walker (0.7 km, 20th largest), and Holcim (Midfield Facility, 5.2 km, 15th largest; Holcim at US Steel, 1.4 km, minor PM emissions). The evidence linking this source complex with fine PM concentrations at WYL includes:

- Proximity and magnitude of emissions.
- Moderately enhanced $PM_{2.5}$ concentrations with winds from the southwest.
- Enhanced concentrations of certain metals (chromium, iron, manganese, nickel, and potassium) having an association with fine mass and occurring with a southwesterly direction of origin of winds.
- Highly elevated concentrations of chromium, iron, manganese, nickel, and potassium on Mondays through Thursdays and low levels on Fridays through Sundays.
- Elevated concentrations of calcium, iron, and manganese in fence-line samples.

W. J. Bullock, Inc., Certainteed, and Other Metal-Processing Facilities. W.J. Bullock (nominally minor emissions in 2003) and Certainteed (17th largest) are located approximately 0.6 km southeast and east, respectively, of WYL. The W. J. Bullock, Inc. facilities produce secondary non-ferrous metal products, which include brass, bronze and aluminum ingots. Zinc ingots are used as additives for brass production, along with scrap and copper. Tin and lead are also additives for making products. Zinc and lead are more volatile than other metals, so they will have a tendency to be released preferentially to other metals in non-ferrous metal processes. The evidence linking these facilities or sources in this geographical area with fine PM concentrations at WYL includes:

- Proximity.
- Elevated fine PM mass concentrations at WYL associated with winds from the northeast and the southeast.
- Highly elevated concentrations of zinc, chlorine, sodium, and lead at WYL, nearly all associated with winds from the east or southeast.[6] These elements exhibited their lowest mean levels on Saturdays (i.e., consistent with weekend process shutdown).
- Extremely elevated concentrations of zinc and lead in samples collected adjacent to W. J. Bullock.

Transportation

The degree to which transportation sources affect either NBHM or WYL is not known quantitatively, and cannot be differentiated from other sources influencing the sites based on inspection of PM composition data, or wind-concentration roses. There is some evidence from carbon speciation studies and from receptor modeling of the NBHM data that on average, the contribution of OC to $PM_{2.5}$ is about 2 to 11 percent from diesel truck exhaust, and 2 to 22 percent from gasoline exhaust, based on a few measurements made in the fall of 2003 and winter of 2004 (e.g. Zheng et al., 2005; Liu et al. 2004,

[6] Elevated zinc concentrations also occurred on some samples associated with winds from the northwest, thus indicating one or more additional sources. The alternative Zn sources to N-NW could not be identified as a specific facility, nor could they be accounted for from diesel transportation exhaust emissions or brake lining dust.

2006a). From receptor modeling, a vehicle contribution at NBHM is estimated to be about 16 percent of the $PM_{2.5}$ mass concentration (Liu et al., 2006b).

References

Liu, W.; Wang, Y.; Russell, A.; Edgerton, E.S. 2004. Atmospheric aerosol over two urban-rural pairs in the southeastern United States: chemical composition and possible sources. *Atmos. Environ.* 39: 4453-4470.

Liu, W.; Wang, Y.; Russell, AS.; Edgerton, E., 2006a. Enhanced Source Identification of Southeast Aerosols Using Temperature Resolved Carbon Fractions and Gas Phase Components. Submitted to *Atmos. Environ.*

Liu, W.; Lee, S.; Wang, Y.; Russell, A.; Edgerton, E., 2006b. Source Apportionment of PM2.5 at Four SEARCH Sites: Comparison Between PMF and CMB. Submitted to *Atmos. Environ.*

Zheng, M; Lin, K; Edgerton, E.; Schauer, J.; Dong, M.; Russell, A., 2005. Spatial Distributions of Carbonaceous Aerosol in the Southeastern U.S. using Molecular Markers and Carbon Isotope Data. To be published in *J. Geophys. Res.*